Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills.
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

Q.1.

A. Attempt any THREE of the following: **12**

a) Define Bus. Explain the classification of bus.

Bus: In transmission system is defined as transmission path on which power are dropped off or picked up at every load attached to the line ---------(1M)

Types of buses.................... (1 mark each)

In power system for load flow studies following types of buses are considered.

i. Slack bus / Reference bus
ii. Load bus / PQ bus
iii. PV bus / Generator bus
iv. Voltage controlled bus

Importance of each bus --

In a power system each bus or node is associated with four quantities magnitude of voltage - P,Q,V and its phase angle 'δ',

In load flow studies two out of four quantities are specified and remaining two are required to be obtained through load flow solutions. Depending upon which quantities have been specified, the buses are classified as follows.

I Load Bus : - At this bus power is injected or delivered to load. Hence real & reactive component of power is specified. At this bus voltage is allowed to vary within the permissible limit and phase angle 'δ' is not important from consumers point of view. This is also called as PQ bus. Power ejected from bus is considered as negative.

II Generator bus : - At this bus power generated is injected into the system. Hence the magnitude of voltage corresponding to its rating are specified from load flow solution and it is required to find out Q & S. This is also called as PV bus

III Voltage Control bus: This bus generally considered as PV bus, but there is physical difference. Voltage control bus has voltage control capabilities and uses tap-changing transformer & static VAR compensators where as generator bus has generator.

Here $P_G = 0$ & $Q_G = 0$, hence $P_i = -P_D$, $Q_i = -Q_D$.

V_i are known and δ_i is unknown.

IV Slack Or Swing Or Reference Bus : - In power system power is injected by generator bus and power is delivered or ejected at Load bus. So whatever losses takes place in the system remains unknown, until the load flow solution is complete. Hence one of the generator bus is made to take additional real and reactive power to supply transmission losses. This bus is known as slack or swing bus. At this bus the magnitude of bus voltage and phase angle are specified while P & Q are obtained through the load flow solution.

Type Of Bus	Specified quantities specification	Quantities Obtained Unknown Quantities
Load bus	P,Q	V, δ
Generator bus	P, V	Q, δ
Voltage control bus	V,P,Q	Δ
Slack bus	V, δ	P,Q

b) State the data required for load flow studies.
(1/2 Mark, each point)

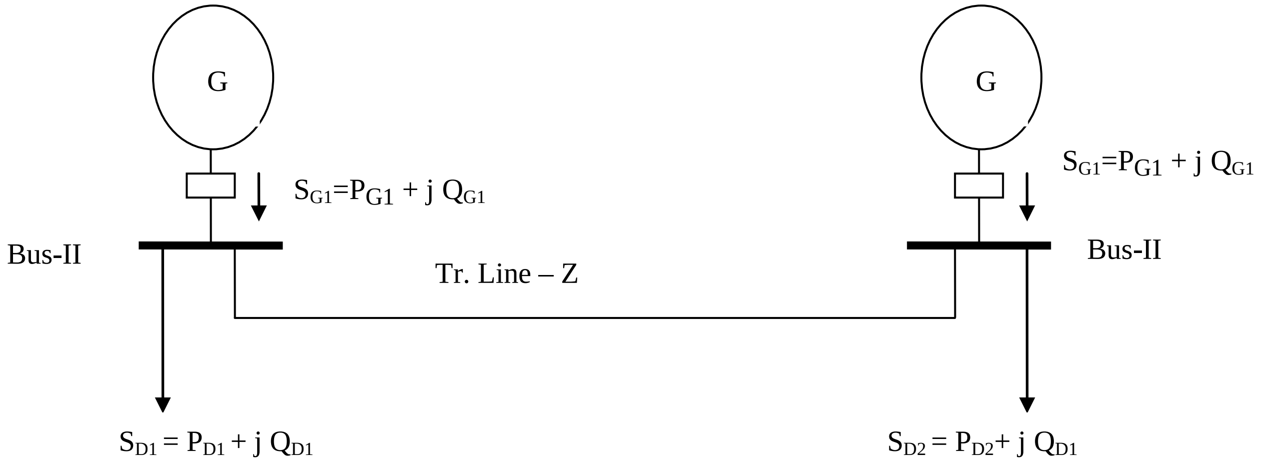
- Single line diagram of a power system.
- Transmission line data -
  (a) Line parameters – Series impedance (z) in per unit shunt admittance (y) thermal limits of the line.
  (b) Length of the line.
  (c) Identification of each line and its II equ. Ckt.
- Transformer ratings, impedance and tap setting are required. Quite often it may be necessary to adjust voltages on one or both sides of the transformers to maintain the potential levels at the neighboring buses within specified limits. For achieving this, auto and double winding transformers with provision for tap changing on h. v. side or used so as to facilitate smoother control.
- At certain buses, static capacitors are used for voltage level improvement their admittance value should be clearly specified.
- Some of lines may be tuned for the purpose of voltage stabilization, by using shunt reactors or series capacitors. Their values should be made available.
- Depending upon no. 07 buses in the system bus data should be made available : -

Type of bus	No of buses	Bus date
Generator bus		P, (V)
Load bus		P, Q

- If the load flows study is to be carried out for a specified load demand then the most effective manner in which generation can be scheduled at the various buses so as to ensure the desired voltage profile.
  A no. of load flow solutions is possible for different sets of control parameters. It is therefore necessary to define and objective functions so as to ensure the desired voltage profile.

c) With diagram derive the line flow equation for 2-bus system. (4 Marks)

Consider a simple two bus power system as shown in the fig.



Let S_{G1}&S_{G2} be the power injected by the generators in bus – I and bus – II resply which was measured on the h. v. side of the transformers. Let S_{D1}& S_{D2} be the load demands on bus I & bus II resply. Two buses are inter connected by a transmission line having ∏ equivalent ckt. Let $V_1$and V_2 be the voltage at two buses I **&** **II** resply.

Let S_1&S_2 be the bus power which is defined as difference between generated power and load demand.

Hence,

$S_1 = S_{G1} – S_{D1}$

$= (P_{G1} – P_{D1}) + j\,(Q_{G1} – Q_{D1})$

$= P_1 + j\,Q_1$

And

$S_2 = S_{G2} – S_{D2}$

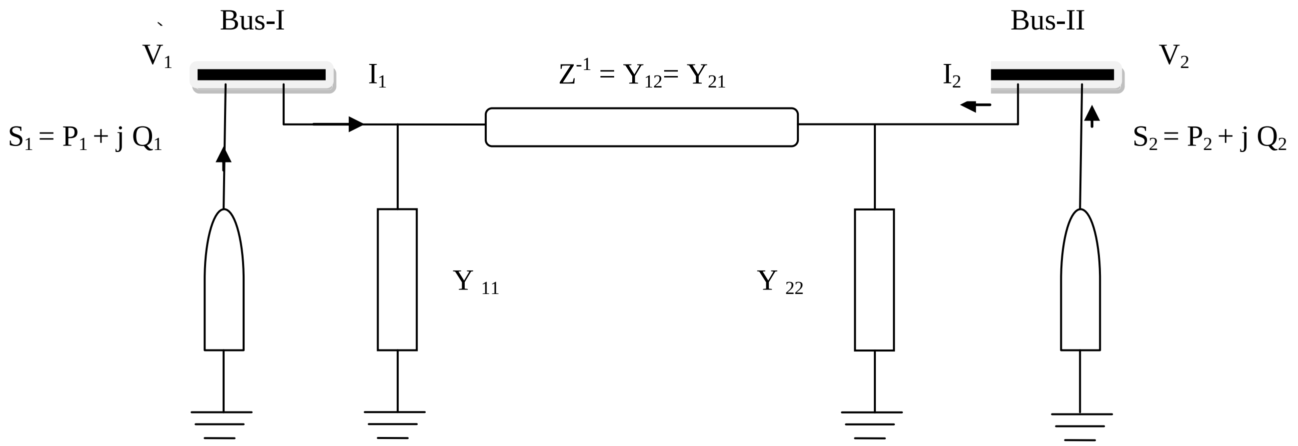
$= (P_{G2} – P_{D2}) + j\,(Q_{G2} – Q_{D2})$

$= P_2 + j\,Q_2$

This bus power can be considered as the power injected into the bus by a bus power source. Hence equivalent ckt. For the given system can be drawn as follow

Let I_1 – net current entering bus –I_1 I_2 – net current entering bus - II

i. e. bus current of bus - IIi.e. bus current of bus - II



Bus power S_1 can also be written as,

$S_1 = V_{1/} I^*_1$ $I_1^* = S_1/V_1$ $I_1 = S_1^*/V_1^*$

Where I_1 enters tr. Line from bus – I .

By applying KCL at bus – I , we get

$I_1 = V_1 Y + (V_1 - V_2) Y'$

We get

$I_1 = S_1^*/V_1^* = V_1 Y + (V_1 - V_2) Y'$ ----------------- (1)

$I_2 = S_2^*/V_2^* = V_2 Y + (V_2 - V_1) Y'$ ----------------- (2)

The above two = o.s. can be simplified as

$I_1 = V_1 (Y + Y') - Y' V_2$------------------ (3

$I_2 = -Y_1 Y' + (Y+Y') V_2$ ------------------- (3)

Let $Y+Y' = Y_{11} = Y_{22}$

$-Y = Y_{12} = Y_{21}$

Substituting in above equn, we get

$I_1 = Y_{11} V_1 + Y_{12} V_2$ ------------------ (4)

$I_2 = Y_2 V_1 + Y_{22} V_2$ ------------------- (4)

Above eq 7 o.s. can be written in matrix form as,

$$\begin{vmatrix} \mathbf{I_1} \\ \mathbf{I_2} \end{vmatrix} = \begin{vmatrix} \mathbf{Y_{11}} & \mathbf{Y_{12}} \\ \mathbf{Y_{21}} & \mathbf{Y_{22}} \end{vmatrix} + \begin{vmatrix} \mathbf{V_1} \\ \mathbf{V_2} \end{vmatrix} \quad \text{------------ } \mathbf{(5)}$$

i.e**. I bus = Y bus V bus** ---------------- (6)

I bus = bus current vector

V bus = bus voltage vector

Y bus – bus admittance matrix $= \begin{vmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{vmatrix}$

Above equn. Can also be written as

I bus Z bus = V bus ------------------- (7)

Where Z bus – bus admittance matrix $= \begin{vmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{vmatrix} = \text{Y bus}^{-1}$

By knowing Z bus or Y bus, if V bus is given then we can calculate I bus easily or vise versa.

d) Define (i) power system stability (ii) power system instability.

i. **Power System Stability**: **(2M)**
It is ability to return to normal or stable operation after having been subjected to some form of disturbance.

ii. **Power System instability: (2M)**
It is the state of power system when it fails to return to its normal operation or stable operation after experiencing some form of disturbances.
OR
Instability means a condition denoting loss of synchronism or falling out of step.
It is status of system when it loses its normal stable operating condition because of increase in power demand beyond the capacity of power generation

B. Attempt any ONE of the following: 6

a) Explain the concept of load compensation and line compensation.
(Load compensation 3M; line compensation 3M)

Load compensation is the management of reactive power to improve power quality i.e., V profile and pf. Here the reactive power flow is controlled by installing shunt compensating devices (capacitors/ reactors) at the load end bringing about proper balance between generated and consumed reactive power. This is most effective in improving the power transfer capability of the system and its voltage stability. It is desirable both economically and technically to operate the system near unity power factor. This is why some utilities impose a penalty on low pf loads. Yet another way of improving the system performance is to operate it under near balanced conditions so as to reduce the flow of negative sequence currents thereby increasing the system's load capability and reducing power loss.

Line compensation

Ideal voltage profile for a transmission line is flat, which can only be achieved by loading the line with its surge impedance loading while this may not be achievable, the characteristics of the line can be modified by line compensator so that:

1. Ferranti effect is minimized.
2. Under excited operation of synchronous generators is not required.
3. The power transfer capability of the line is enhanced. Modifying the characteristics of a line(s) is known as line compensation.

Various compensating devices are:

1. Capacitor
2. Capacitor and inductor
3. Active voltage source (synchronous generator)

When a number of capacitors are connected in parallel to get the desired capacitance, it is known as a bank of capacitors, similarly, a bank of inductors. A bank of capacitors and inductors can be adjusted in steps by switching (mechanical).

Capacitors and inductors as such are passive line compensators, while synchronous generator is an active compensator. When solid-state devices are used for switching off capacitors and inductors, this is regarded as active compensation.

b) Explain how voltage control can be done by (i) Reactive Power injection (ii) Transformers.

i) Reactive power injection - (3M)

- Most of the equipments especially at 400KV and above are operated close to the present limits of design and are operated with a voltage profile of ±5%
- Most of the loads absorb lagging VARs to supply magnetizing current of x'mers, induction motors etc. At the time of peak load, vars demanded by loads greatly exceed vars which can be transmitted over the lines therefore additional equipment is necessary to generate lagging VARs
- Shunt capacitance of the line absorbs loading vars. At the time of lighter loads lagging vars. produced by lines are much larger than required by consumer loads. This surplus lagging vars. are absorbed by additional equipment to keep voltage profile within limits.
- Therefore it is necessary to provide additional equipment to generate or absorb vars. Shunt connected inductances absorbs lagging vars. and shunt capacitor generates lagging vars.

ii) Transformers: (3M)

- Regulating Transformer: ………. Location – Distribution Substations,
- Tap changing transformer (OLTC)… Location- Intermediate Distribution Substations.
- Booster transformer: …. Location- HV and EHV transmission lines

Q.2. Attempt any FOUR of the following: 16

a) State the effect of change in voltage level on consumers.

Effect of variation in voltage on consumers (Any four points, 1 mark each)

1. The consumers demand rated supply to all equipments to his premises. Due to variation in the supply voltage the current drawn by the equipment varies. When supply voltage decreases beyond the limit the current drawn by equipment increases & efficiency decreases. As a result performance of the equipment also reduces its life.
2. The induction motor which is commonly used as industrial drive develops the torque which depends on supply voltage $\therefore T \propto V^2$. Hence large variation in supply voltage leads to more variation in torque developed .So far small variation in supply voltage the performance of motor gets affected and as a result the quality of product & the process gets affected.
3. In the lighting system the luminous output of lamp sources depends on supply voltage. Light flux of a lamp depends on voltage, with the voltage fluctuation light flux varies strongly As supply voltage decreases the luminous output of lamp decreases with more fluctuation in supply voltage reduces life of lamp also reduces.
4. Nowadays the more sophisticated equipments are used e.g computers which are very much sensitive towards supply parameters. Fluctuation in supply voltages damages these instruments permanently.

b) Write the S.L.F.E. for two bus system.

➢ **SLFE equations:-**

$S_1^{\,*} = V_1^{\,2}\, Y_{11}\, L\text{œ}_{11} + Y_{12}\, V_2\, V_1 L(\delta_2 - \delta_1) = P_1 - j\, Q_1$ $P_1 = V_1^{\,2}\, Y_{11} \operatorname{Cos} \text{œ}_{11} + Y_{12}\, V_2\, V_1 \operatorname{Cos} (\delta_2 - \delta_1)$ $Q_1 = (V_1^{\,2}\, Y_{11} \operatorname{Sin} \text{œ}_{11} + Y_{12}\, V_2\, V_1 \operatorname{Sin} (\delta_2 - \delta_1)$	$S_2^{\,*} = V_2^{\,2}\, Y_{22}\, L\text{œ}_{22} + Y_{21}\, V_2\, V_1 (\delta_1 - \delta_2) = P_2 - j\, Q_2$ $P_2 = V_2^{\,2}\, Y_{21} \operatorname{Cos} \text{œ}_{22} + Y_{21}\, V_2\, V_1 \operatorname{Cos} (\delta_1 - \delta_2)$ $Q_2 = (V_2^{\,2}\, Y_{22} \operatorname{Sin} \text{œ}_{11} + Y_{12}\, V_2\, V_1 \operatorname{Sin} (\delta_1 - \delta_2)$

For a simple two bus system Load flow equations can be written as….

$P_1 = V_1^{\,2}\, Y_{11} \operatorname{Cos} \text{œ}_{11} + Y_{12}\, V_2\, V_1 \operatorname{Cos} (\delta_2 - \delta_1) \;\; = (P_{G1} - P_{D1})$ **-----2marks**

$Q_1 = \; -[\; (\, V_1^{\,2}\, Y_{11} \operatorname{Sin} \text{œ}_{11} + Y_{12}\, V_2\, V_1 \operatorname{Sin} (\delta_2 - \delta_1) \; = \; - (Q_{G1} - Q_{D1})$ **--2 marks**

V_1, V_2….V_n are the bus voltages
δ_1, δ_2…. are load angles with reference to bus-1, bus-2 and so on.
Y_{11}, Y_{22}….. **are self admittance with reference to bus-1, bus-2 and so on.**
Y_{12}, Y_{21}…. **are Mutual admittance with reference to bus-1, bus-2 and so on**
S_1, S_2……**complex power at bus-1, bus-2.**
P_1, P_2……..**Real power at bus-1, bus-2.**
Q_1, Q_2…….**Reactive power at bus-1, bus-2.**

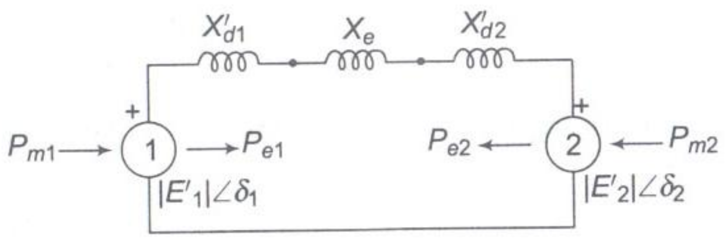
c) With the help of a model, explain the stability studies for simple two machine model. (Diagram 2M, Explanation 2M)

The case of two finite machines connected through a line(X_e) is illustrated in figure where one of the machine must be generating and the other must be motoring. Under steady condition, before the system goes into dynamics,

$P_{m1} = -\, P_{m2} = P_m$

And the mechanical input/output of the two machines is assumed to remain constant at at these values throughout the dynamics (governor action assumed slow). During steady state or in dynamic condition, the electrical power output of the generator must be absorbed by the motor (network being lossless). Thus at all time.

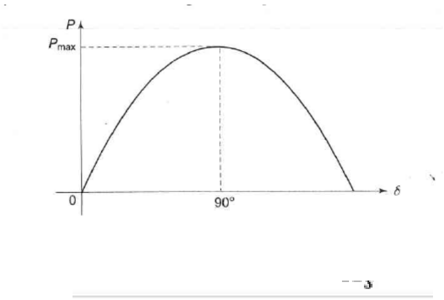
$P_{e1} = -\, P_{e2} = P_e$



Two-machine system

d) State the significance of power angle curve with the help of diagram.
(Explanation 4M, Each point 1M)

The plot of P versus delta shown in Fig. , is called the power angle curve.



$$P = \frac{|E_f|\,|V_t|}{X_s} \sin \delta$$

Significance of power angle curve--power angle curve helps.

- to find Maximum power limit
- to study the performance of transmission system at various load conditions
- Indicate stability status of system
- to study steady state & transient state stability condition of power system
- to determine max possible power flow to the system
- To study Real power balance & its impact on load angle (delta) .

e) Explain the turbine speed governing system with the help of diagram.
(Diagram 2M, Explanation 2M)

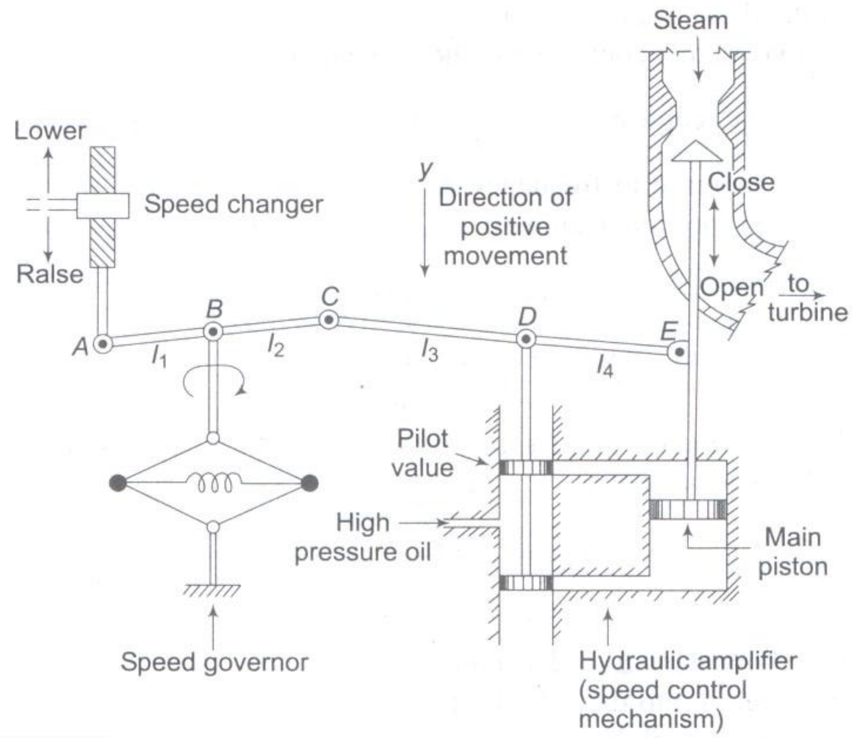
The system consists of the following components:

Fly ball speed governor:
This is the heart of the system which senses the change in speed (frequency). As the speed increases the fly balls move outwards and the point B on linkage mechanism moves downwards. The reverse happens when the speed decreases.

Hydraulic amplifier:
Iit comprises a pilot valve and main piston arrangement. Low power level pilot valve movement is converted into high power level piston valve movement. This is necessary in order to open or close the steam valve against high pressure steam.

Linkage mechanism:
ABC is a rigid link pivoted at B and CDE is another rigid link pivoted at D. this link mechanism provides a movement to control valve in proportion to change in speed. It also provides a feedback from the steam valve movement (link 4).

Speed charger:
It provides a steady state power output setting for the turbine. Their downward movements open the upper pilot valve so that more steam is admitted to the turbine under steady conditions (hence more steady power output). The reverse happens for upward movement of speed changer.



Turbine speed governing system (Reprinted with permission of McGraw-Hill Book Co, New York, from Olle I. Elgerd: Electric Energy System Theory: An Introduction, 1971,

f) Explain the procedure of load forecasting by load curve.
(Explanation 4M, Any four points)

- Collection of past historical data in the form of load curve or load duration curve helps load forecasting
- The nature of load curve is governed by geographical location, season, amount of load demand & time schedule.
- Identification of specified load pattern by comparing load curves of different days during several years
- Depending upon load demand at various time duration planning of power generation can be done based on generation capacity of different power plants
- To satisfy power demand in load curve lad is distributed among the different power plants depending upon fuel availability.(base load/ peak load)
- Constant load --base load & peak load ----hydro or renewable

Q.3. Attempt any FOUR of the following: 16

a) State the advantages of synchronous compensation over static compensation.
(Any four, 1M each)

1) The control is fast and continuous.
2) A drop in voltage causes the synchronous compensation to supply greater VARs
3) The inertia of synchronous compensator improves system stability and reduces the effect of sudden changes in land.
4) It is economical above 10mVAR
5) It provides compensation only by varying excitation.
6) It can provide lagging as well as leading VARs

b) State the information obtained from load flow studies.
(Any Four, 1M each)

1) We get MW and MVAR flow in the various parts of the system network.
2) We get information about voltages at various buses in the system
3) We get information about optional load distribution.
4) Impact of any change in generation on the system.
5) Influence of any modification or extension of the existing circuits on the system loading.
6) It also gives information for choice of appropriate rating and tap setting of the power transformer in the system.
7) Influence of any change in conductor size and system voltages level on power flow.

c) State the need of load flow analysis in power system.
(Any four, IM each)

A load flow study gives magnitude & phase angle of the voltage at each bus, real and reactive power flow through transmission. Lines, current flow through transmission lines.

1) For designing the power system.
2) For operation of the system.
3) For future expansion of the system to meet increase in the demand.
4) For inter connecting the two systems to meet the load demand.
5) For analyzing both normal and abnormal (means outage of tr. Lines or transformer or gen. units) operating conditions.
6) For analyzing the initial conditions of the system when the transient behavior of the system is to be studied.
7) Transmission lines can carry only certain amount of current and we must make sure that we do not operate these links too close to their stability or thermal limits so LFA helps to know the amount current flowing through various lines in the network.
8) LFA also helps in maintaining the stability of the system by giving the information about real, reactive power flow in the system.

d) Define: (i) transient stability & state its limits. (ii) Steady state stability and its limits.

Transient stability: (1M)
Transient stability is the ability of the power system to regain or maintain equilibrium conditions after experiencing a large sudden disturbance.
Transient state stability limit: **(1M)**
It refers to max possible flow of power trough a point without loss of stability when system experiences a large sudden disturbance.

Steady state stability: (1M)
When the power system has capacity to regain and maintain equilibrium condition (synchronous speed) after a small slow disturbance such as road variation or changes in load condition occurs, then the phenomenon is known as steady state stability.

Steady State stability limit: (1M)
It is defined as max power which can flow through point in the system without causing loss of stability, when system experiences a small disturbance.

e) Fig (a) shows a 4-bus system. Treat the bus 4 as reference bus. Find the bus admittance matrix. P.U. reactances are shown in fig.

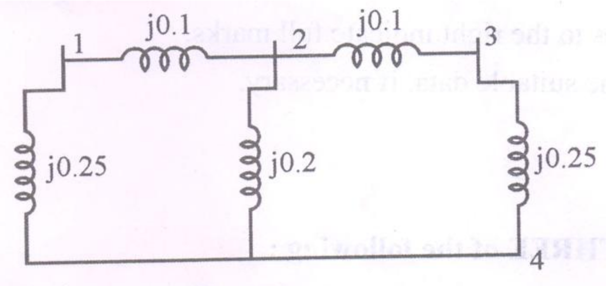


Fig.-(a)

$$y_{12} = \frac{1}{j0.1} = j10 = y_{23} = y_{21} = y_{32}$$

$$y_{13=}y_{31} = 0, y_{14} = \frac{1}{j0.25} = j4$$

$$y_{11=}y_{33} = -j4$$

$$y_{22} = -j5$$

$$Y_{11} = y_{11} + y_{12} = -j4 - j10 = j14$$

$$Y_{12} = Y_{21} = -y_{12} = -j10$$

$$Y_{22} = y_{22} + y_{21} + y_{23} = -j5 - j10 - j10 = j25$$

$$Y_{13} = Y_{31} = -y_{31} = 0$$

$$Y_{23} = Y_{32} = -y_{23} = j10$$

$$Y_{33} = y_{33} + y_{31} + y_{32} = -j4 - j0 - j10 = j14$$

$$Y_{bus} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix}$$

$$= \begin{bmatrix} j14 & -j10 & 0 \\ -j10 & j25 & -j10 \\ 0 & -j10 & j14 \end{bmatrix}$$

Q.4.

A. Attempt any THREE of the following: 12

a) Compare shunt compensation to series compensation.
(Any 4 points, 1Mark each)

Shunt Compensation	**Series Compensation**
Costly/expensive	Cheaper
More losses	Less losses
Better voltage profile control	Less voltage profile control
Effective in off-peak period	Not effective in off peak period
More chance of voltage collapse	Less chance of voltage collapse
Fast control over temporary over voltages	Less control over temporary over voltages
Shunt compensation not improve stability	series compensation improve stability

b) Write the swing equation & state the meaning of each term in it.
(Equation 1M, meaning of each term 3M)

$$\frac{md^2\delta}{dt^2} = P_a = P_m - P_e$$

$where\ \ m = angular\ momentum,$

$P_m = mechanical\ power\ input,$

$P_e = electrical\ power\ output,$

$P_a = accelerating\ power,$

$\delta = angular\ displacement\ of\ rotor$

c) Derive the SLEF in general form.

SLEF in general form for a two buses system can be written as
Power at bus I is

$$P_1 = V_1^2 y_{11} \cos \propto_{11} + V_1 V_2 y_{12} \cos(\delta_2 - \delta_1 + \propto_{12})$$

$$Q_1 = -V_1^2 y_{11} \sin \propto_{11} - V_1 V_2 y_{12} \sin(\delta_2 - \delta_1 + \propto_{12})$$

If the system is having three buses then power at bus I can be written

$$P_1 = V_1^2 y_{11} \cos \propto_{11} + V_1 V_2 y_{12} \cos(\delta_2 - \delta_1 + \propto_{12}) + V_1 V_3 y_{13} \cos(\delta_3 - \delta_1 + \propto_{13})$$

$$Q_1 = -V_1^2 y_{11} \sin \propto_{11} - V_1 V_2 y_{12} \sin(\delta_2 - \delta_1 + \propto_{12}) - V_1 V_3 y_{13} \sin(\delta_3 - \delta_1 + \propto_{13})$$

If the system is having 'n' number of buses then

$$P_1 = V_1^2 y_{11} \cos \propto_{11} + V_1 V_2 y_{12} \cos(\delta_2 - \delta_1 + \propto_{12}) + \cdots + V_1 V_n y_{1n} \cos(\delta_n - \delta_1 + \propto_{1n})$$

$$= \sum_{n=1}^{n} V_1 V_n y_{1n} \cos(\delta_n - \delta_1 + \propto_{1n})$$

$$Q_1 = -\sum_{n=1}^{n} V_1 V_n y_{1n} \sin(\delta_n - \delta_1 + \propto_{1n})$$

Power at K^{th} bus can be written as

$$P_k = \sum_{n=1}^{n} V_k V_n y_{kn} \cos(\delta_n - \delta_k + \propto_{kn})$$

$$Q_k = -\sum_{n=1}^{n} V_k V_n y_{kn} \sin(\delta_n - \delta_k + \propto_{kn})$$

$$P_k = V_k \sum_{n=1}^{n} V_n y_{kn} \cos(\delta_n - \delta_k + \propto_{kn})$$

$$Q_k = -V_k \sum_{n=1}^{n} V_n y_{kn} \sin(\delta_n - \delta_k + \propto_{kn})$$

$$I_{bus} = \begin{Bmatrix} I_1 \\ I_2 \\ .. \\ .. \\ I_n \end{Bmatrix}$$

$$V_{bus} = \begin{Bmatrix} V_1 \\ V_2 \\ .. \\ .. \\ V_n \end{Bmatrix}$$

$$Y_{bus} \quad \begin{bmatrix} Y_{11}.....Y_{1n} \\ .... \\ .... \\ Y_{n1}....Y_{nn} \end{bmatrix}$$

…………..(1M)

We have, $I_{bus}=Y_{bus}.V_{bus}$

The bus current Ik is replaced by injected bus power S_k

$S_k=P_k+j_{Qk}$

$S_k=V_k^* I_K=P_k+j_{Qk}$

$P_k+j_{Qk}/V_k^*=I_k$

Thus the equation may be given as

$P_k+j_{Qk}/V_k^*=I_k$

$P_k+j_{Qk}/V_k^*=Y_{k1}V_1= Y_{k2}V_2+……….+ Y_{kn}V_n$

$P_k+j_{Qk}= Y_{k1}V_1 V_k^*- Y_{k2}V_2 V_k^*-………… Y_{kn}V_n V_k^*=0$

(3M)

d) Define the load shedding and state its governing factor.

Load shedding: (02 marks)

When generators get overloaded beyond the maximum mechanical power input, it becomes necessary to interrupt some load to save the system from loss of stability. This process is called load shedding. In majority of the power systems, load shedding is automatically performed because of time available is insufficient for manual operation.

Factors affecting load shedding :(any four 1/2 marks each)

1. Imbalance between power demand & power generation
2. Sudden rise or fall in demand/load
3. Major faults like 3-phase faults, L-L faults turn into instability condition
4. Sharing of power so as to increase run time of critical loads
5. To reduce wastage of energy and max. demand

B. Attempt any ONE of the following: 6

a) Discuss the relationship between real power and frequency for a simple two bus. (6M)

Effect of Real power on Frequency:

If there is variation in the real power flow through the system that is reflected in variation of frequency. Now the real power flow in a system includes generated power, load connected the system and power demanded by the system. The system also requires some power to overcome losses in it.

Losses in the system includes

1) Losses in the transmission lines (I^2R)
2) Losses due to corona
3) Losses in Transformer, generator etc.

Load frequency fluctuations are to be minimized to satisfy the consumers and to operate system in the stable condition. In order to control the frequency variation with respect to the variations in power demand a signal has to be raised to generator in order to decrease or increase its output, so that generated power will match with power demand and frequency gets adjusted to accepted value.

$$P_D \uparrow \rightarrow P_g < P_D \rightarrow N \downarrow \rightarrow f \downarrow \xrightarrow{a\ signal\ to\ generator} P_g \uparrow \rightarrow f \uparrow$$

Whenever the power demand increases and power generation fall back, as a result speed of the generator reduces and reflected in falling of frequency. Now raise a signal to governor of generator in order to increase input power of turbine so that generation output increases and will match with demand and supply frequency also rises to accepted value.

$$P_D \downarrow \rightarrow P_g > P_D \rightarrow N \uparrow \rightarrow f \uparrow \xrightarrow{a\ signal\ to\ generator} P_g \downarrow \rightarrow f \downarrow$$

Similarly when (P_d) powers demand decreases, frequencies increases and now raise a signal governor in order to decrease power generation so that supply frequency gets adjusted with the accepted value. This complete process is known as “load frequency control”.

Hence in modern power system the power is expressed in terms Mw/Hz. means that, it is megawatt load when suddenly comes on the system, drop the frequency by 1Hz. and vice versa.
For eg. 500Mw/Hz means when the power demand on the system increases by 500Mw, the supply frequency fall by 1Hz. Or when power demand on the system decrease by 500Mw then supply frequency rises by 1Hz.

OR

The frequency is closely related with real power balance in the system network. But power demands are continuously varying with rising or falling trend. Hence steam input to turbo generators must, therefore be continuously regulated to meet the real power demand. If any change in real power balance, it will result into variation of supply frequency which is highly undesirable. The maximum permissible variation in power frequency is $\pm$ 0.5 Hz.

Load frequency fluctuations are to be minimized to satisfy the consumers and to operate system in the stable condition. In order to control the frequency variation with respect to the variation in power demand a signal has to be raised to generator in order to decrease or increase its output ,so that generated power will match with power demand and frequency gets adjusted to accepted value.

$$\mathbf{P_D \uparrow \rightarrow P_g < P_D \rightarrow N \downarrow \rightarrow f \downarrow} \xrightarrow{} \text{a signal to generator} \quad \mathbf{P_g \uparrow \rightarrow f \uparrow}$$

Whenever the power demand increases and power generation falls back, as a result speed of the generator reduces and reflected in falling of frequency. Now raise a signal to governor of generator in order to increase input power of turbine so that generation output increases and will match with demand and supply frequency also rises to accepted value .

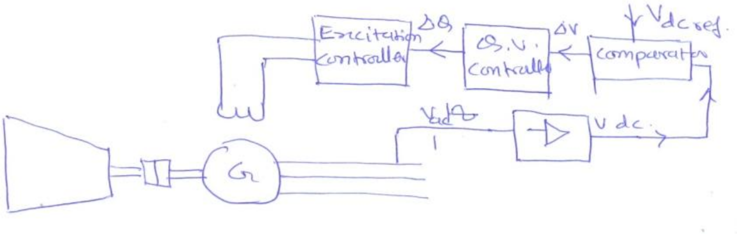
$$P_D \downarrow \rightarrow P_g < P_D \rightarrow N \uparrow \rightarrow f \uparrow \xrightarrow{} \text{a signal to governor} \quad P_g \downarrow \rightarrow f \downarrow$$

Similarly when (P_d) powers demand decreases, frequencies increases and now raise a signal to governor in order to decrease power generation so that supply frequency gets adjusted with the accepted value .This complete process is known as “Load frequency control”.

Hence in modern power system the power is expressed in terms Mw/Hz. Ii means that, it is megawatt load when suddenly comes on the system, drops the frequency by 1 Hz. and vice versa.

For e.g 500Mw /Hz means when the power demand on the system increases by 500 Mw , the supply frequency falls by 1Hz. Or when power demand on the system decreases by 500Mw then supply frequency rises by 1 Hz.

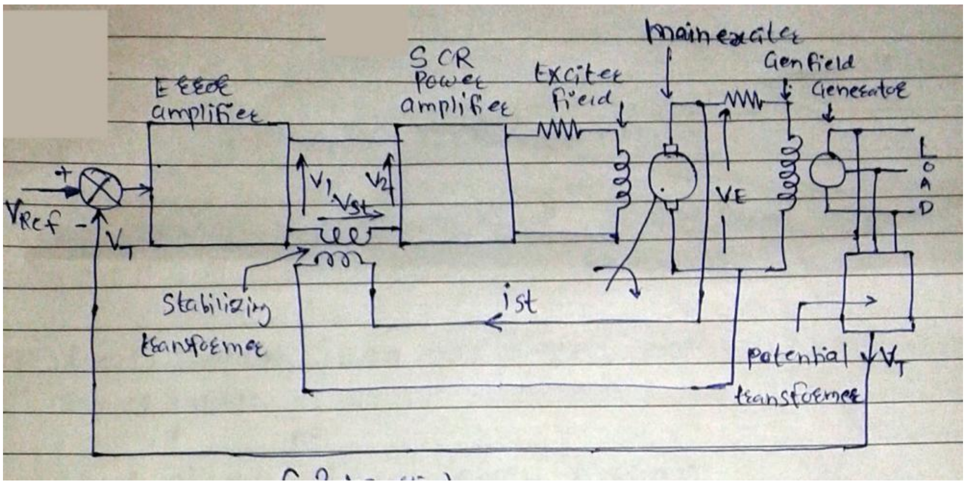
b) Draw the diagram of automatic voltage control and explain each block in it. (Diagram 3M; Explanation 3M)



The objective of voltage controller is to exert control of excitation of generator. A voltage sensor senses the terminal voltage and converts into an equivalent D.C. Voltage. This D.C. voltage is compared with reference voltage by comparator. The output of comparatorΔV is given as input to Q-V controller, which transfers into reactive power signal ΔQ and feeds it to excitation controller. This in turn modifies the generator terminal voltage.

OR

Potential transformer: it gives simple terminal volt V_T
Differencing device: it gives the actuating error
$E=V_{Ref} - V_T$
The error initiates the corrective action of adjusting the alternator excitation.
Error amplifier: it demodulates and amplifies the error signal. Its gain is K_a.
SCR power amplifier and exciter field: it provides the necessary power amplification to the signal for controlling the exciter field.
Alternator: its field is excited by the main exciter voltage V_E under no load it produces a voltage proportional to field current.
Stabilizing transformer: T_{ef} and T_{gf} are large enough time constants to impair the systems dynamic response. It is well known that the dynamic response of a central system can be improved by the internal derivative feedback leap. Its output is fed at the input terminals of SCR power amplifier.

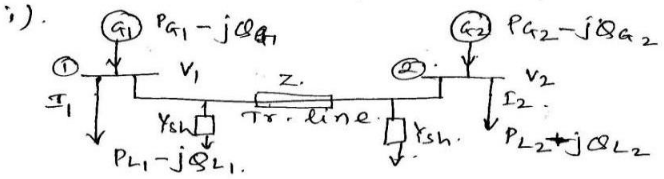


Q.5. Attempt any FOUR of the following: 16

a) Describe the steps involve in deriving SLEF for a bus system. (4M)

). Load flow equations for two bus system:-

i).



Consider two bus system connected with two gen. stations and loads at each bus. and connected by π network.

ii). Current in bus ① $I_1 = V_1 Y_{sh} + \frac{V_1 - V_2}{Z}$

current in bus ② $I_2 = V_2 Y_{sh} + \frac{V_2 - V_1}{Z}$

where $Y_{sh} = j/x_C$, $Z = R + jx_L$, $\alpha = R/x_L$.

$x_L = e^{j(\pi/2 - \alpha)}$.

ii). $V_1 = |V_1| e^{j\delta_1}$, $V_2 = |V_2| e^{j\delta_2}$.

substituting in eqn of I_1 and I_2 we get

$$\frac{(P_{G1} - P_{L1}) + j(Q_{G1} - Q_{L1})}{|V_1| e^{-j\delta_1}} = |V_1| e^{j\delta_2} \frac{j}{x_C} + \frac{|V_1| e^{j\delta_1} - |V_2| e^{j\delta_2}}{X_L e^{j(\pi/2 - \alpha)}}.$$

iii) $(P_{G1} - P_{L1}) + j(Q_{G1} - Q_{L1})$

$$= j\frac{|V_1|^2}{x_C} + \frac{|V_1|^2}{x_L} e^{-j(\pi/2 - \alpha)} - \frac{|V_1||V_2|}{x_L} e^{j(\delta_2 - \delta_1 + \alpha - \pi/2)}.$$

iv) After simplifying we get,

$(P_{G1} - P_{L1}) + j(Q_{G1} - Q_{L1})$.

$$= j\left\{\frac{|V_1|^2}{x_C} - \frac{|V_1|^2}{x_L}\cos\alpha + \frac{|V_1||V_2|}{x_L}\cos[\alpha - (\delta_1 - \delta_2)]\right\} + \left\{\frac{|V_1|^2}{x_L}\sin\alpha - \frac{|V_1||V_2|}{x_L}\sin[\alpha - (\delta_1 - \delta_2)]\right\}.$$

v) Equate real and imaginary terms and simply

$$P_{G1} - P_{L1} - \frac{|V_1|^2}{x_L}\sin\alpha + \frac{|V_1||V_2|}{x_L}\sin[\alpha - (\delta_1 - \delta_2)] = 0.$$

$$Q_{G1} - Q_{L1} - \frac{|V_1|^2}{x_C} + \frac{|V_1|^2}{x_L}\cos\alpha - \frac{|V_1||V_2|}{x_L}\cos[\alpha - (\delta_1 - \delta_2)] = 0$$

vi)

$$P_{G2} - P_{L2} - \frac{|V_2|^2}{x_L}\sin\alpha + \frac{|V_1||V_2|}{x_L}\sin[\alpha + (\delta_1 - \delta_2)] = 0.$$

$$Q_{G2} - Q_{L2} - \frac{|V_2|^2}{x_C} + \frac{|V_2|^2}{x_L}\cos\alpha - \frac{|V_1||V_2|}{x_L}\cos[\alpha + (\delta_1 - \delta_2)] = 0.$$

b) Define: (i) Dynamic state Stability (ii) Overall stability.

i. Dynamic state stability: **(2M)**
It is the condition where system is analyses for a period of 4-10 seconds following a large disturbance such as a short circuit or loss of generation or loss of load. The ability of a power system to maintain stability under continuous small disturbances is investigated under the name of Dynamic Stability (also known as small-signal stability).

OR

Dynamic state stability
When synchronous machines are operated along with fast acting voltage regulator, the stability limits of the system are high than when rather slow acting regulators are used that stability is called dynamics stability.

ii. Overall stability: (2M)
It is the stability of the power system when synchronism of one of working generator has been lost the normal operating condition can be reestablished without disconnection of major elements.

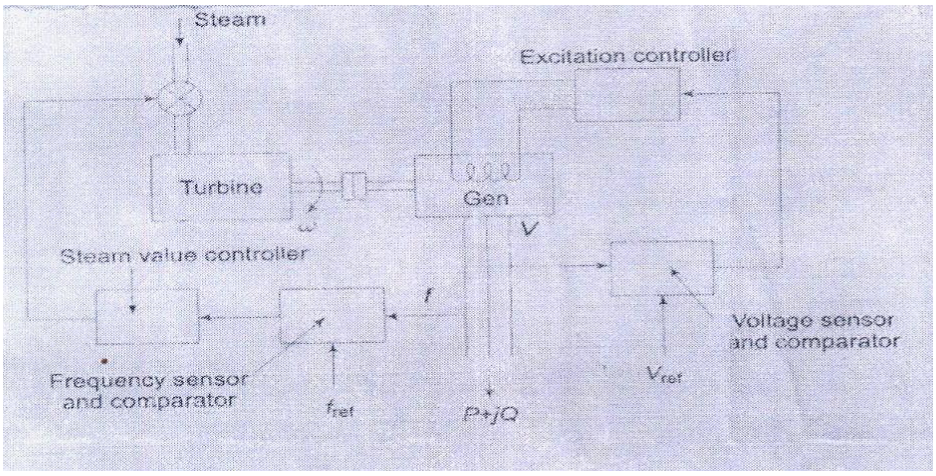
OR

Modern power system uses automatic control devices and therefore it is to be tested for its ability to remain in synchronism under steady state as well as transient state condition under both prior and after occurrence of the disturbance such operating condition a power system is called as overall stability condition.

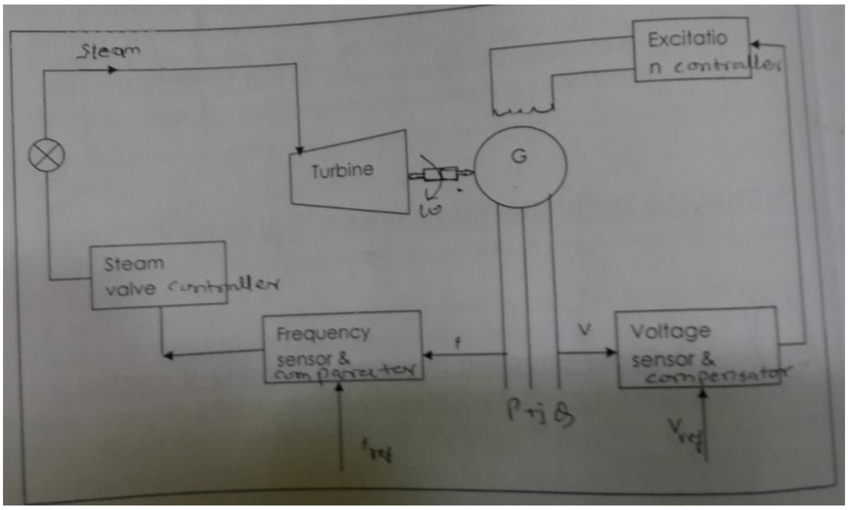
OR

The overall stability denotes the power system remain stable under the disturbance. Usually power system experience short and steady as well as long duration and sudden disturbances. These disturbances will disturb the equilibrium of the system. When the system has a capability to remain in equilibrium or synchronism under all the disturbance can be treated as overall stability. Hence the overall stability of the system will be combine study of steady state and transient stability analysis.

c) Draw the diagram of automatic load frequency and voltages regulator control system.
(Labeled Diagram 4M)



OR



d) List the methods of voltage control.
(Any four points 1M for each)

Following are the method of voltage control in power system.

1. By tap changing transformers.
   i. Off load tap changing
   ii. On load tap changing
2. By shunt reactors
3. By shunt capacitors
4. By static shunt compensation
5. By synchronous condenser
6. By series capacitors
7. By flexible AC transmission (FACT) devices.

e) State the environmental and social factors in load forecasting.

1.Environmental factors : (2M)

i. Weather variables.
ii. Temperature.
iii. Wired speed.
iv. Cloud cover.
v. Fog indication/ visibility.
vi. Summer, winter, Rainy sessions.

2.Social factors : (2M)

i. Factory strikes.
ii. Popular TV programs & their duration.
iii. Terrorist attacks.
iv. Festivals.
v. Visits of VIP.
vi. Public holidays/school vacations.

f) Describe the concept of economic load dispatch and optimum load dispatch.

Economic Dispatch: - (2M)
The main components of power system are power generation, power transmission and finally power distribution. Now when it comes to sending power to consumers, the main aim is to minimum the cost (both of the generation transmission and distribution). Keeping this in mind the term economic load dispatch is coined. There are mainly two parts connected with economic load dispatch. The first one is unit commitment and the second one is online load dispatch. Unit commitment deals with the connection of generating units with the certain networks depending upon the cost involved for transmitting and distribution power.

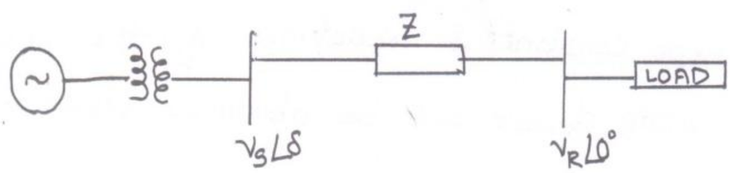
Optimum Dispatch: - (2M)
Optimum load dispatch deals with the transmission losses relating with the power system. In general when a network is connected with more than one feeders or generating unit the common convention is to deliver power to the network from the generator units eventually that's where the concept of optimum load dispatch this ensures the minimum cost involved with the distribution of power.

Q.6. Attempt any FOUR of the following: 16

a) Explain the need of forecasting in power system.
(Explanation 4M)

1. Electricity is the most preferred form of energy & electrification is an ongoing process.
2. Demand for electricity tends to grow more rapidly for economic development
3. Increasing demand of electricity is due to several factors such as population growth, growth of per capital income migration to urban areas and increase in energy using products.
4. Understanding electricity demand, planning and control is critical for all countries.
5. Power system planning involves forecast of future load of both demand and energy.
6. Forecasting is useful to determine capacity of generation transmission and distribution and decide generation facilities required.
7. Load forecasting is useful for establishing policy for procurement of capital equipment and fuel.
8. Forecasting is gaining importance due to increasing scarcity of electrical energy along with more powerful computing equipment and software.

b) Derive the equation of maximum power flow under steady state condition.



………………………………**1 mark**

Complex power at receiving end is given by,

$P_R = \frac{V_S.V_R}{B}\cos(\beta - \delta) - \frac{AV_R{}^2}{B}\cos\beta - \alpha)$

Consider a transmission line whose shunt admittance are neglected, i.e. Y=0.

Now, Equivalent circuit of medium & long transmission line is similar to that short transmission line having GCC as, A=1∠0° & B=Z∠B.
……………………………………………2 mark

Subtitling in above Equation we get,

$$P_R = \frac{V_S . V_R}{Z} \cos B - \delta) - \frac{V_{R^2}}{Z} \cos \beta$$

$$= \frac{V_R}{Z} [V_S . \cos(B - \delta) - V_R \cos \beta] \times \frac{Z}{Z}$$

$$= \frac{V_R}{Z^2} [V_S . Z \cos(B - \delta) - V_R . R] \ldots . . (as\ Z \cos \beta = R) \ldots \ldots . (1)$$

'P_R' will be maximum if $\frac{dP_R}{d\delta} = 0$ ……………………………………….**1 mark**

$\therefore \frac{dP_R}{d\delta} = \frac{V_R}{Z} [V_S . Z \sin(B - \delta)] = 0$

$\therefore \sin(B - \delta) = 0$

∴β-δ=0; ∴β=δ

∴Substituting in Eq^n in (1), we get ……………………**1 mark**

$$P_{R_{max}} = \frac{V_R}{Z^2} [V_S . - V_R . R]$$

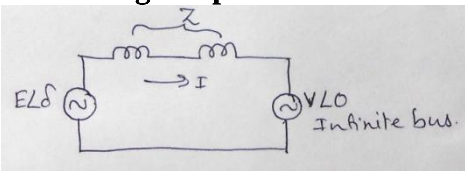
$$= \frac{V_R}{(R^2+X^2)} \left[V_S . \sqrt{R^2 + X^2} - V_R . R\right]$$

$$P_{R_{max}} = \frac{V_S . V_R}{\sqrt{R^2}+X^2} - \frac{V_{R^2} . R}{(R^2+X^2)}$$ ………………………..**1 mark**

This is max steady state power.

OR

Consider equation of current through impedance Z as



$$I = \frac{|E|\angle\delta - |V|\angle 0}{z\angle\theta} = \frac{|E|}{|Z|}\angle\delta - \theta - \frac{|V|}{|Z|}\angle - \theta$$

$$I^* = \frac{|E|}{|Z|}\angle\theta - \delta - \frac{|V|}{|Z|}\angle\theta ------ (\mathbf{1M})$$

$$s = VI^* = \frac{|V||E|}{|Z|}\angle(\theta - \delta) - \frac{|V|}{|Z|}\angle\theta$$

$$P_e = R_e[S] = \frac{|V||E|}{|Z|}\cos(\theta - \delta) - \frac{|V|^2}{|Z|}\cos\theta$$

$$z = R + JX = \sqrt{R^2 + X^2}\angle\tan^{-1}(\frac{X}{R})$$

$$\alpha = (90 - \theta) = \sin^{-1}\left(\frac{R}{Z}\right) ------ (\mathbf{1M})$$

$$P_e = \frac{|V||E|}{|Z|}\cos(90 - \alpha - \delta) - \frac{|V|^2}{|Z|}\cos(90 - \alpha)$$

$$= \frac{|V||E|}{|Z|}\sin(\alpha + \delta) - \frac{|V|^2}{|Z|}\sin\alpha ---- (\mathbf{1M})$$

$$P_e \text{ } is \text{ } maximum \text{ } when \text{ } (\alpha + \delta) = \frac{\pi}{2}$$

$$hence, P_{emax} = \frac{|V||E|}{\sqrt{R^2 + X^2}} - \frac{|V|^2}{\sqrt{R^2 + X^2}} \times \frac{|R|}{\sqrt{R^2 + X^2}}$$

$$if \text{ } E = V$$

$$P_{emax} = \frac{|V|^2}{\sqrt{R^2 + X^2}} - \frac{-|V|^2 R}{R^2 + X^2} ---- (\mathbf{1M})$$

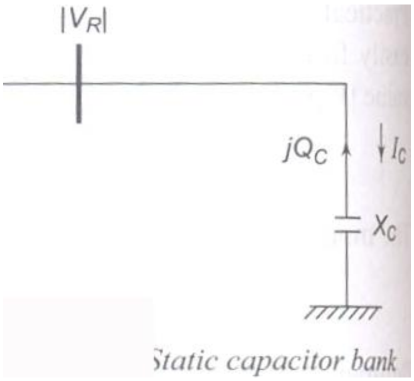
c) State the different methods of voltage control by reactive power injection. Explain any one.

Types of voltage control by reactive power injection:

1. Static VAR generators (Static capacitor bank).
2. Rotating VAR generators (synchronous condenser).

1. Static VAR generators (Static capacitor bank).

It is nothing but a bank of three-phase static capacitors and /or inductors. With reference to figure, if $|V_R|$ is in line kV, and X_c is the per phase capacitive reactance of the capacitor bank on an equivalent star basis, the expression for the VARs fed into the line can be derived as under.



$$I_C = j\frac{|V_R|}{\sqrt{3}X_C}kA$$

$$jQ_C(three\ phase) = 3\frac{|V_R|}{\sqrt{3}}(-I^*c)$$

$$= j3 \times \frac{|V_R|}{\sqrt{3}} \times \frac{|V_R|}{\sqrt{3}X_C}MVA$$

$$\therefore Q_C\,(three\ phase) = \frac{|V_R|^2}{X_C}MVA$$

$$if\ inductors\ are\ employed\ instead, VARs\ fed\ into\ the\ line\ are$$

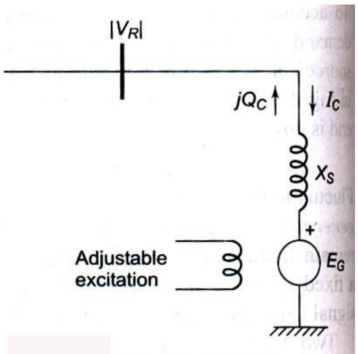
$$Q_C\,(three\ phase) = \frac{|V_R|^2}{X_L}MVA$$

Under heavy load conditions, when positive VARs are needed, capacitor banks are employed; while under light load conditions, when negative VARs are needed, inductor banks are switched on.

The following observations can be made for static VAR generators:

1. Capacitor and inductor bank can be switched on in steps. However, stepless (smooth) VAR control can now be achieved using SCR (silicon Controlled Rectifier) circuitry.
2. Since Q_c is proportional to the square of terminal voltage, for a given capacitor bank, their effectiveness tends to decrease as the voltage sags under full load conditions.
3. If the system voltage contains appreciable harmonics, the fifth being the most troublesome, the capacitors may be overloaded considerably.
4. Capacitor acts as short circuit when switched ‘On’.
5. There is a possibility of series resonance with the line inductance particularly at harmonic frequencies.
6. Rotating VAR generators (synchronous condenser).

   It is nothing but synchronous motor running at no load and having excitation adjustable over a wide range. It feeds positive VARs into the line under overexcited conditions and feeds negative VARs when under excited. A machine thus running is called a synchronous condenser.



Rotating VAR generation

Figure shows a synchronous motor connected to the receiving end bus bars and running at no load. Since the motor draws negligible real power from the bus bars, E_G and V_R are nearly in phase. X_S is the synchronous reactance of the motor which is assumed to have negligible resistance. If $|E_G|$ and $|V_R|$ are in line kV, we have

$$I_C = \frac{(|V_R| - |E_G|\angle 0^0}{\sqrt{3} \times jX_S} kA$$

$$jQ_C = 3\frac{|V_R|\angle 0^0}{\sqrt{3}}(-I^*c)$$

$$= 3 \times \frac{|V_R|}{\sqrt{3}}(-\frac{|V_R| - |E_G|}{-jX_S\sqrt{3}})$$

$$= \frac{j|V_R|(|E_G| - |V_R|)}{X_S} MVA$$

$$\therefore Q_C = \frac{|V_R|(|E_G| - |V_R|)}{X_S} MVAR$$

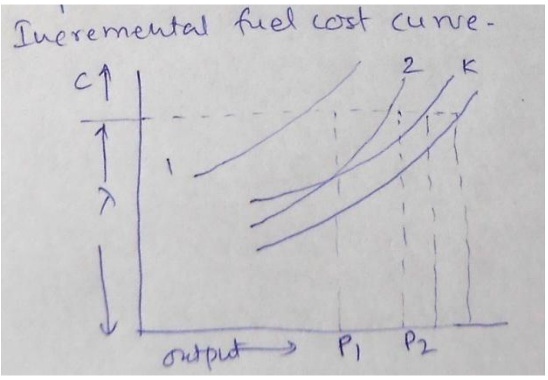
It immediately follows from the above relationship that machine feeds positive VARs into the line when $|E_G|>|V_R|$(overexcited case) and injects negative VARs if $|E_G|<|V_R$ (under excited case). VARs are easily and continuously adjustable by adjusting machine excitation which controls $|E_G|$.

In contrast to static VAR generators, the following observations are made in respect of rotating VAR generators.

These can provide both positive and negative VARs which are continuously adjustable.

VAR injection at a given excitation is less sensitive to change in bus voltage. As $|V_R|$ decreases and ($|E_G|$-| V_R) increase with consequent smaller reduction in Q_C compared to case of static capacitors.

d) Describe economic load dispatch with the help of incremental fuel cost curve. (Diagram 1M, Description 3M)



Consider two generating unit having costs C_1 and C_2 with output $P_1$and P_2.
Total cost C= $C_1 + C_2$
Total output $P=P_1+ P_2$
C_1 and C_2 are fuel cost of two units in Rs. Per hour. The total output P is equal to active power demand and is constant. It is desired to find $P_1$and P_2. So that C is minimum.

$$\frac{dc}{dp_1} = \frac{dc_1}{dp_1} + \frac{dc_2}{dp_1}$$

$dp_2 = -dp_1$ (as $P=P_1+ P_2$)

$$for\ minimum\ total\ cost\ C\ \frac{dc}{dp_1} = 0$$

Hence we get from above equation

$$\frac{dc_1}{dp_1} = \frac{dc_2}{dp_2} = \lambda\ incremental\ cost. where\ \frac{dc_1}{dp_1}\ and\ \frac{dc_2}{dp_2}\ are\ incremental\ costs.$$

Hence loads should be such allocated that the two units operate at incremental cost. This is considered as economic load dispatch.

e) The cost curve of two generating units of a power plant are given as

$$\frac{dc_1}{dp_1} = 0.3p_1 + Rs50/MWh$$

$$\frac{dc_2}{dp_2} = 0.4p_2 + Rs50/MWh$$

Determine fuel cost of each unit for total load on station to be 1000 MW considering economic load dispatch.

The cost curves are

$$\frac{dc_1}{dp_1} = 0.3p_1 + Rs50/MWh$$

$$\frac{dc_2}{dp_2} = 0.4p_2 + Rs50/MWh$$

Total load P_1+P_2=1000MW
P=P_1+P_2=1000MW
Therefore for economic load dispatch

$$\frac{dc_1}{dp_1} = \frac{dc_2}{dp_2} ------ (\mathbf{1M})$$

$$Hence\ 0.3p_1 + 50 = 0.4p_2 + 40$$

$$0.3p_1 + 50 = 0.4(1000 - p_1) + 40$$

$$0.3p_1 + 50 = 400 + 0.4p_1 + 40$$

$$0.3p_1 + 0.4p_1 = 400 + 40 - 50$$

$$0.7p_1 = 390$$

$$p_1 = 557MW ------(\mathbf{1M})$$

$$subsituting\ value\ of\ p_1\ we\ get$$

$$p_2 = 1000 - 557 = 443MW ----(\mathbf{1M})$$

$$the\ incremental\ costs\ of\ each\ unit\ are$$

$$\frac{dc_1}{dp_1} = 0.3(557) + 50 = \frac{217.1Rs}{MWhr} ----(\frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{M})$$

$$\frac{dc_2}{dp_2} = 0.4(443) + 40 = \frac{217.1Rs}{MWhr} ------ (\frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{M})$$